

# Use of MODIS data for Inferring Radiative Fluxes and Applications

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Online Giovanni Workshop  
*September 25-27, 2012***

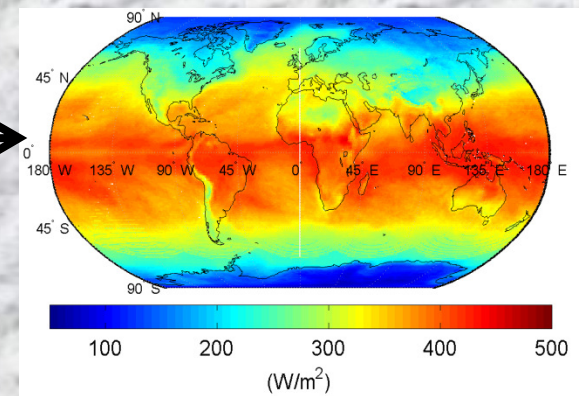




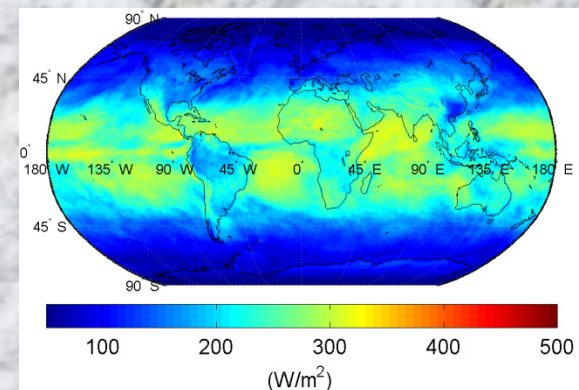
# Brief Review of:

- ❖ Issues and why MODIS?
- ❖ Development, implementation and evaluation of methods to infer radiative fluxes from **MODIS**
- ❖ Use of information in research
- ❖ Sharing results with community

$F_{LW}$



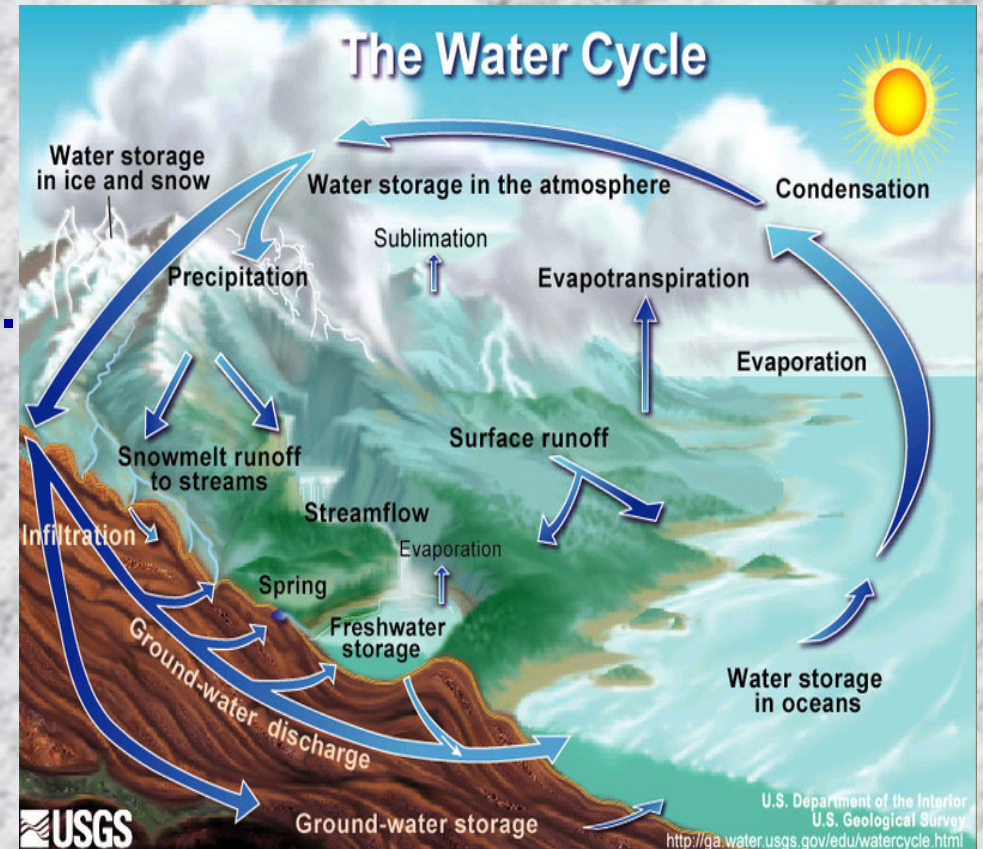
$F_{SW}$





# Need for Information on Radiative Fluxes

- Provide forcing of the climate system
- Used to:
  - ❖ evaluate climate models
  - ❖ improve surface/atmos. parameterizations in global and meso-scale models
  - ❖ allows realistic modeling of the hydrological cycle and carbon dynamics





# Why Satellites?

## Ground Measurements

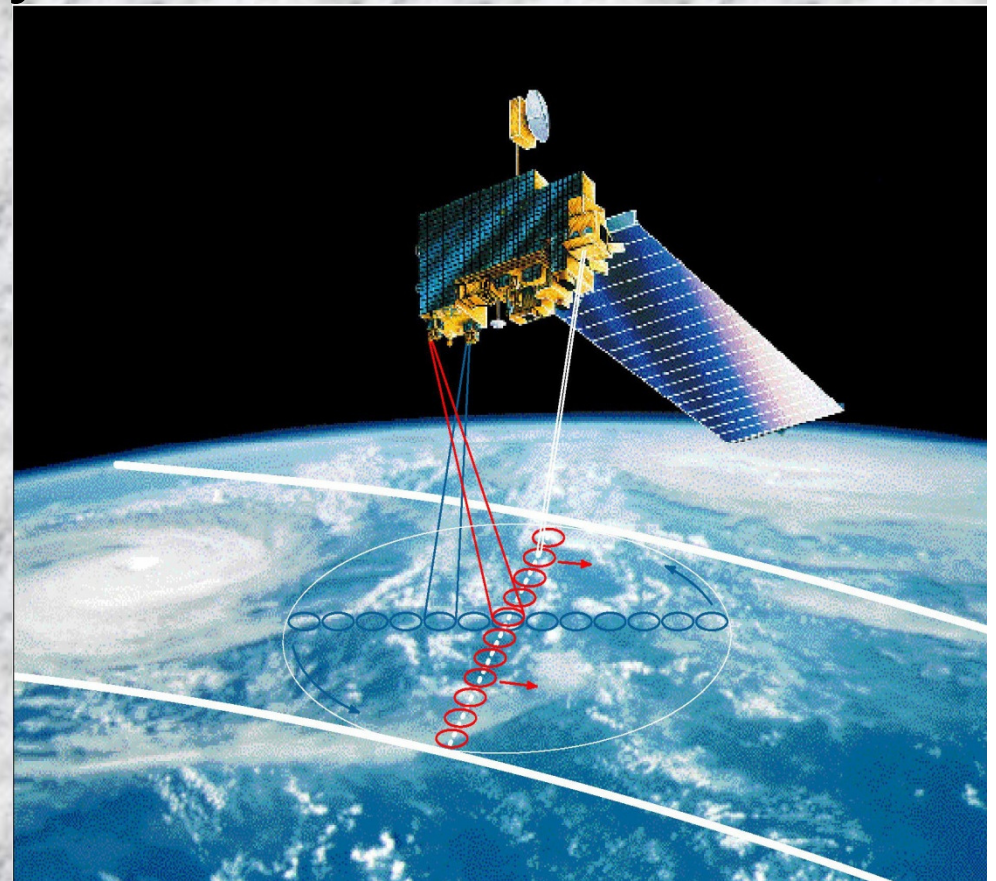
- Limited spatial coverage
- Records of high quality are short

## GCMs

Representation of **clouds** is problematic

## Satellite Observations:

- Global coverage
- Homogenous in space and time
- Same instrument for each system







**Difficulty:** Satellites monitor radiation at the **top of the atmosphere (TOA)**; models are needed to estimate how energy flows from TOA to the earth surface.



# Two approaches to the use of satellite observations to derive surface fluxes

1. Start with radiances (“indirect”) as observed by the satellite; implemented frequently with AVHRR, GOES, METEOSAT, GMS, ISCCP D1/DX at global or regional scales ( $2.5^\circ$ ,  $1^\circ$ ,  $0.5^\circ$ ); at selected regional scales at higher spatial resolution (typically  $0.125^\circ$ )
2. Use products on atmosphere and surface **properties** that have been derived independently (“direct”)



## Why MODIS?

- Several expert teams work on deriving information that is needed to infer **surface radiative fluxes** and it is readily available from **Giovanni**.
- Information is available at  $1^0$  and 5-km resolutions from **same instrument** at the **same time** – **an important advantage** compared to other sources of information used in radiation budget studies.

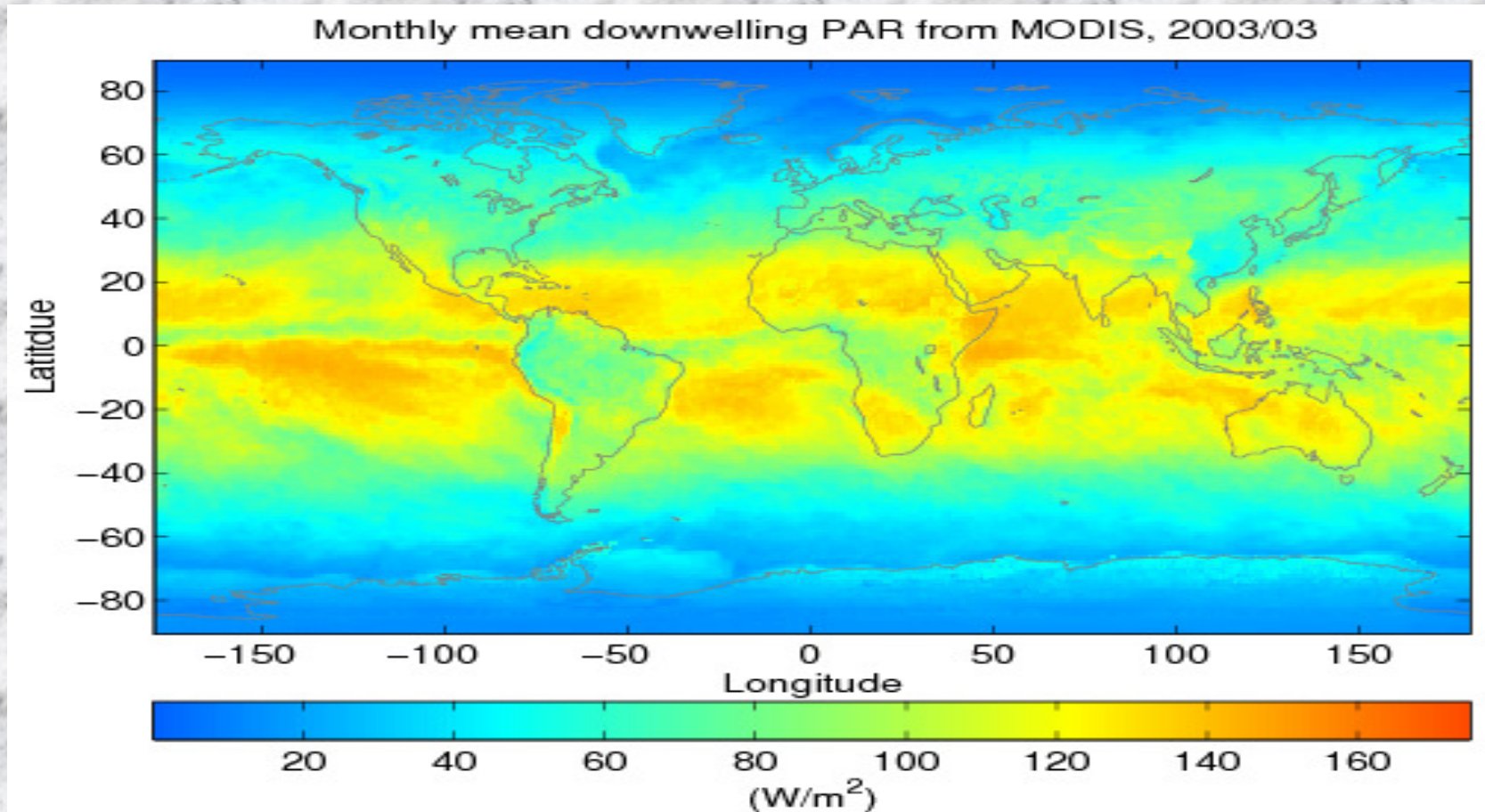


## Benefit to MODIS Products

The use of the MODIS based quantities to derive information that can be verified independently against ground measurements can serve as an independent evaluation of those MODIS products for which measurements are meager (*e.g., cloud amount, cloud optical depth*).



## Developed capabilities to use MODIS for SW radiative fluxes



*Wang, H and Pinker, R. T., 2009. Shortwave radiative fluxes from MODIS: Model development and implementation. JGR-Atmospheres, 114, D20201.*



## MODIS Products from Giovanni Used

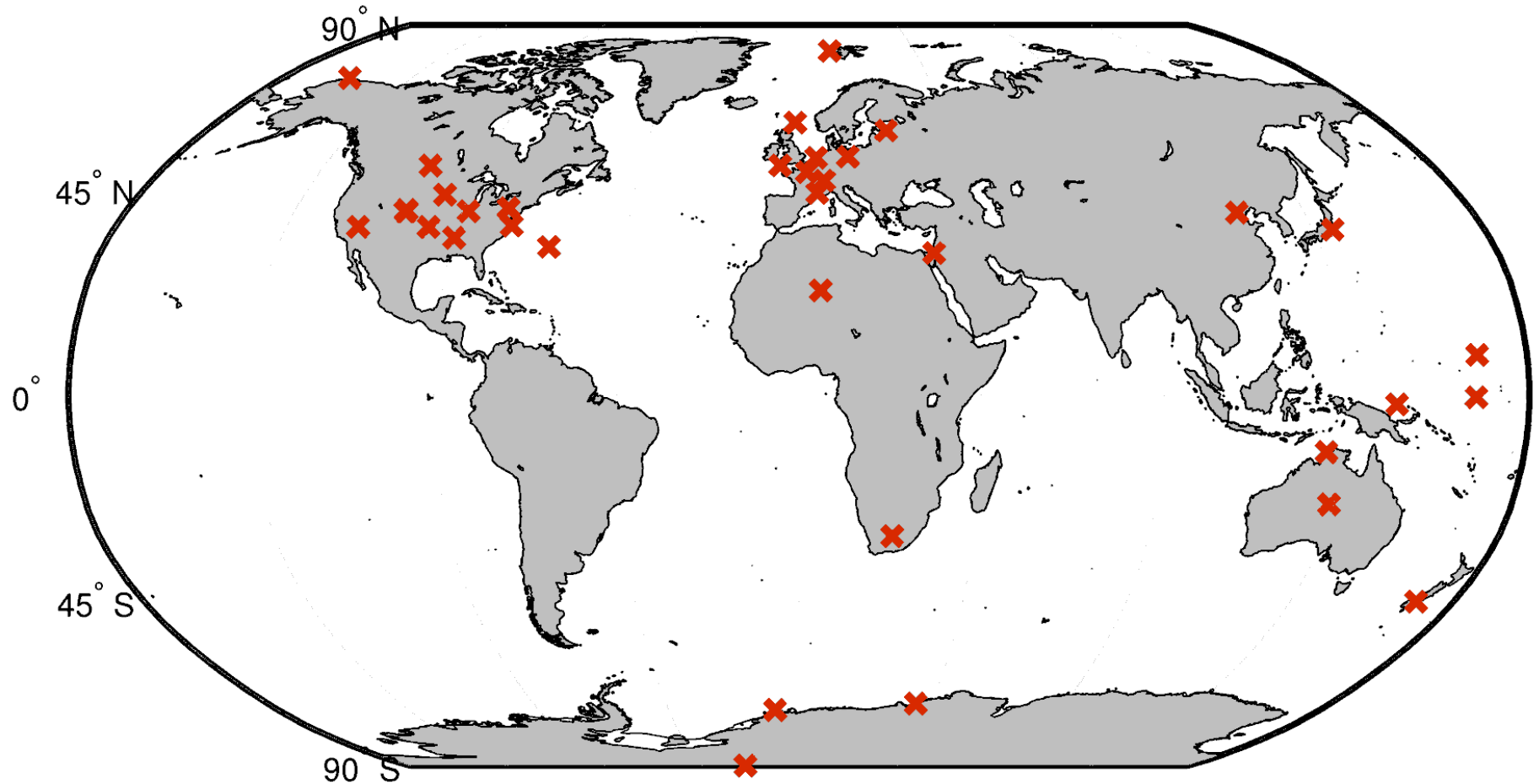
Level-3 MODIS Atmosphere Daily Global Product (MOD08\_D3, MYD08\_D3) contains statistics derived from four Level-2 atmospheric products: aerosol (MOD04, MYD04), precipitable water (MOD05, MYD05), cloud (MOD06, MYD06), and atmospheric profiles (MOD07, MYD07), where MOD denotes data collected from the Terra platform and MYD indicates data collected from Aqua platform (*King et al.*, 1992, 2003). The statistics are sorted into 1 cells on an equal-angle global grid (360 180 cells).



Model input **parameters** taken from Level-3 Atmosphere Daily Global Product **include**: Aerosol Optical Depth for Land and Ocean, Cloud Top Pressure Day, Cloud Optical Thickness Liquid, Cloud Optical Thickness Ice, Cloud Effective Radius Liquid, Cloud Effective Radius Ice, Cloud Effective Radius Undetermined, Cloud Fraction Liquid, Cloud Fraction Ice, Cloud Fraction Undetermined, Cloud Optical Thickness Undetermined, Total Ozone, and Atmospheric Water Vapor. Clouds with undetermined phase are treated as water clouds in the computation of radiative fluxes. Level-3 Atmosphere Global Daily products from both Terra and Aqua used for illustrating results are Collection 005 MODIS data from January 2003 to December 2005.



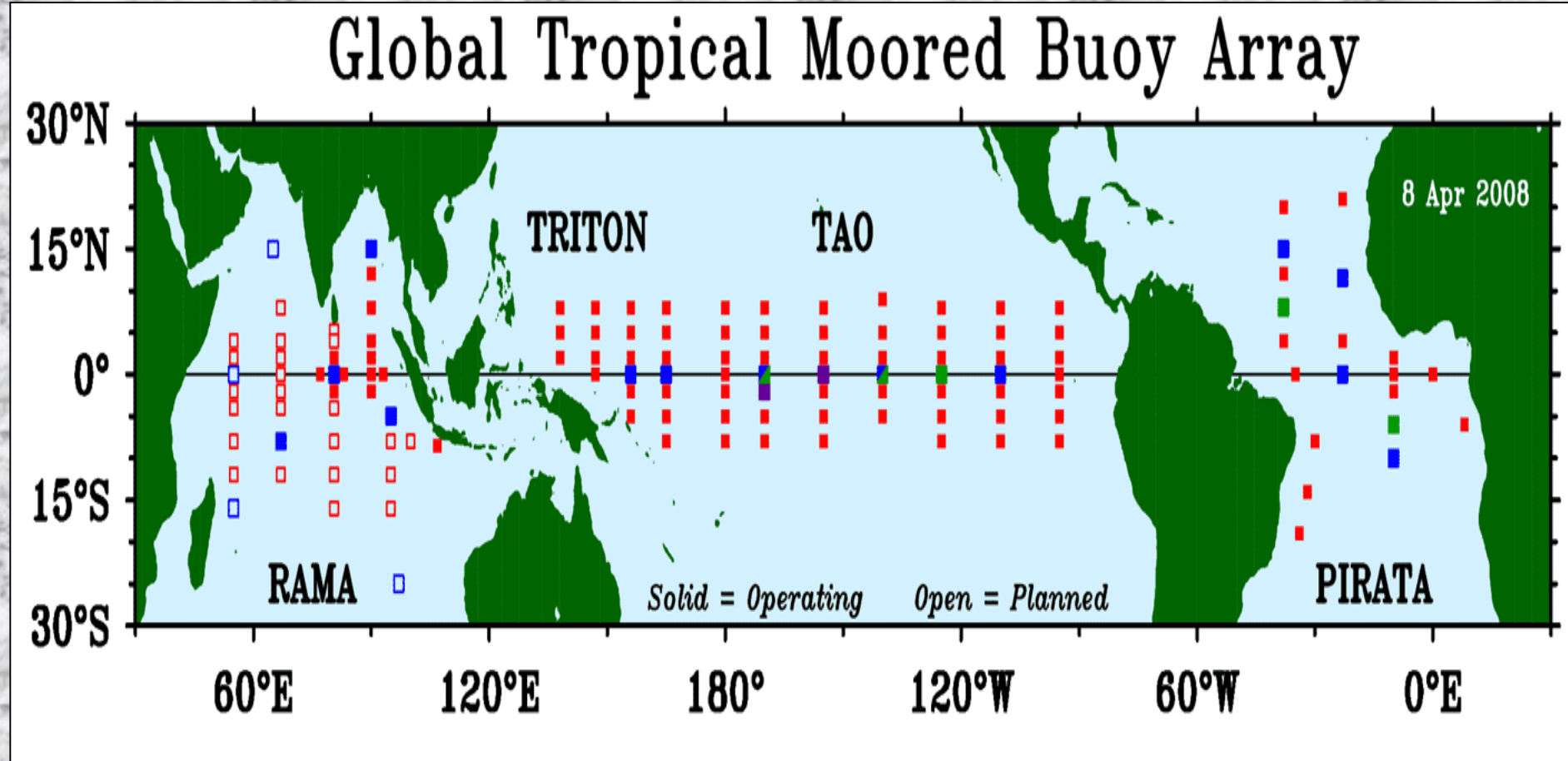
# Ground stations used in evaluation



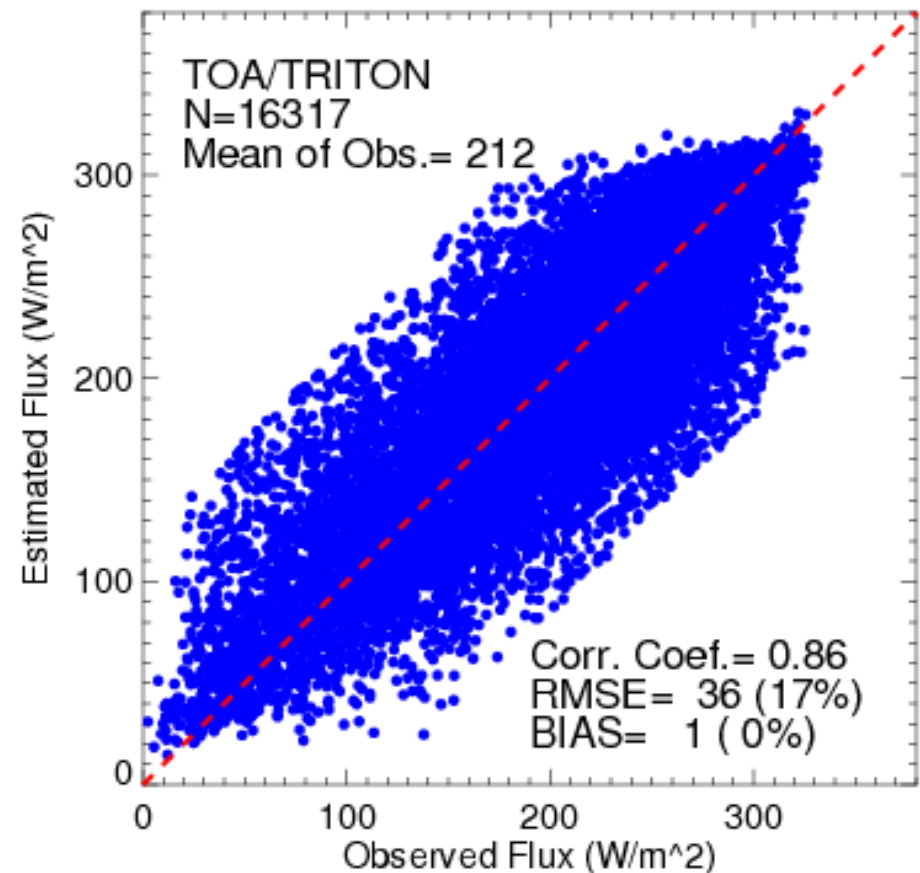
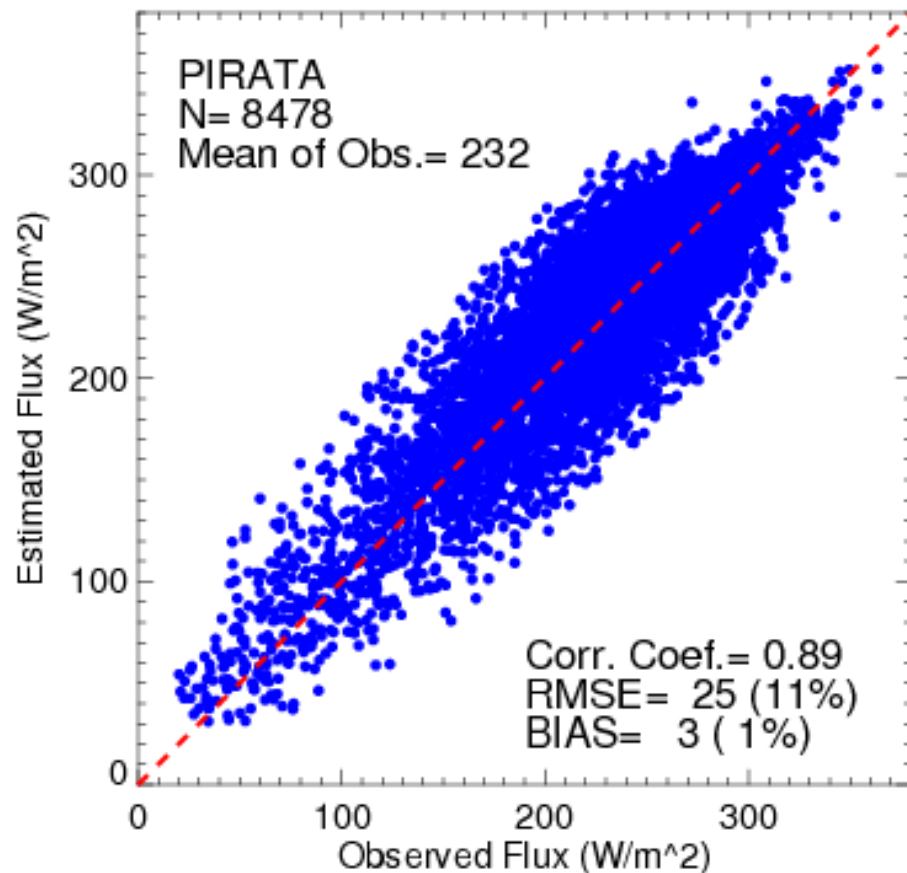
Geographic distribution of Baseline Surface Radiation Network (BSRN) (*Ohmura et al.*, 1998).



## Oceanic stations used in evaluation



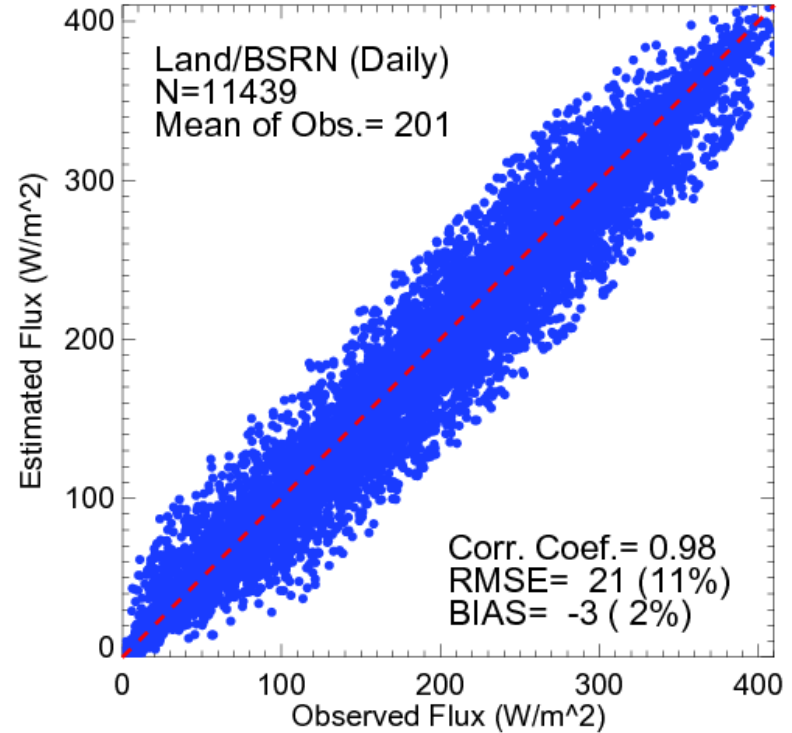
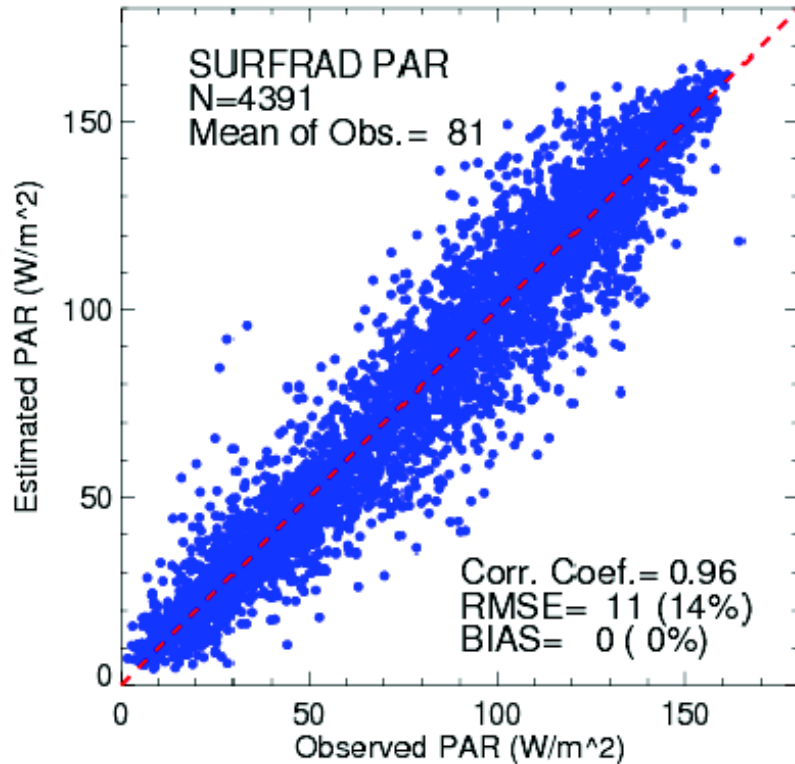
Pilot Research Moored Array in the Tropical Atlantic (PIRATA); Tropical Atmosphere Ocean/Triangle Trans-Ocean Buoy Network (TAO/TRITON) (McPhaden *et al.*, 1998).



Evaluation of daily mean surface SW estimated by UMD/SRB\_MODIS (2003-2005) against PIRATA and TAO/TRITON buoy observations (1997/1979).

*Pinker, R T; Wang, H., Grodsky, S. A., 2009. How good are ocean buoy observations of radiative fluxes? GRL, 36, L10811.*





Daily mean surface downward SW (right) and PAR (left) from UMD/SRB\_MODIS evaluated against all BSRN sites and at six SURFRAD sites for PAR, respectively, 2003-2005 (eliminated were 1.3 % outliers for SW).

Pinker, R T; Wang, H., Grodsky, S. A., 2009. How good are ocean buoy observations of radiative fluxes? GRL, 36, L10811.

# Evaluation of MODIS Radiative Fluxes Using Unique Observations

Examples will be given for:

- ☐ Oceans
- ☐ High latitudes

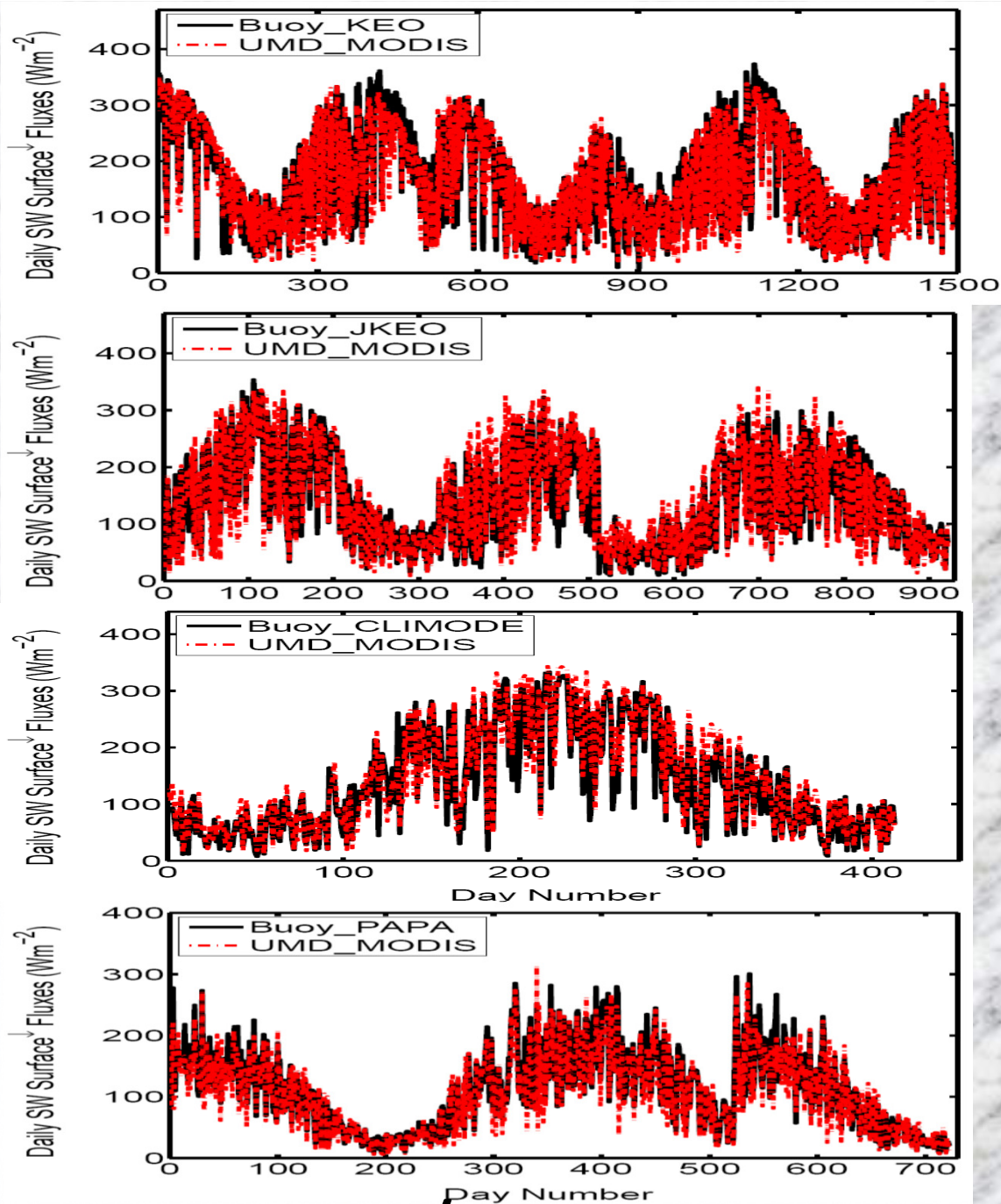


**Barrow, Alaska NOAA's Climate Monitoring & Diagnostics Laboratory  
U.S. Department of Energy's Atmospheric  
Radiation Measurement (ARM) Climate  
Research Facility**



**Weather buoy operated by  
the NOAA National Data Buoy  
Center**





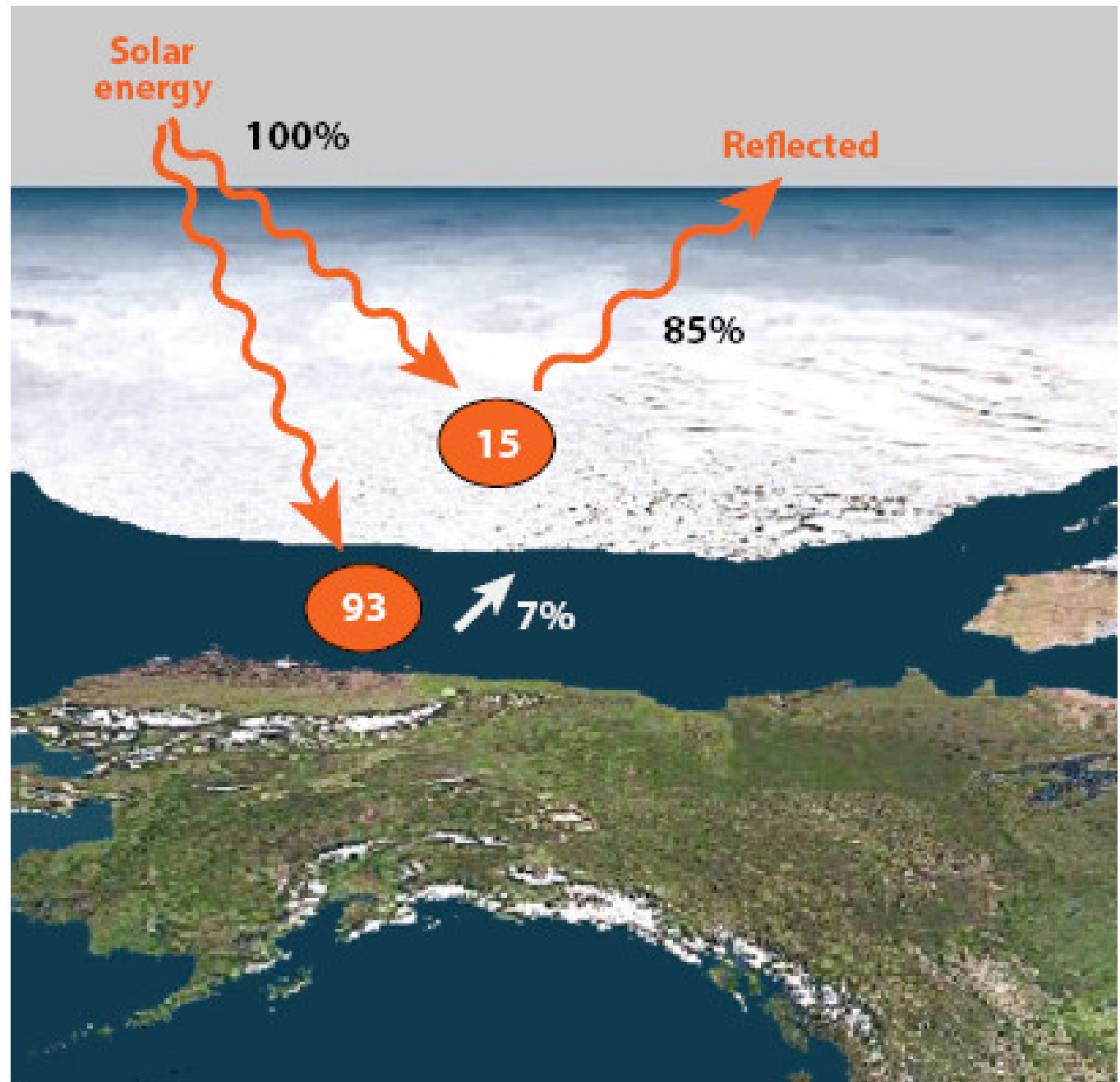
NOAA/PMEL

Evaluation of daily averaged surface downward SW estimated from UMD\_MODIS against buoy observations at  
 (a): KEO (32°N, 145°E)  
 (b): JKEO (38°N, 146.5°E)  
 (c): CLIMODE (38°N, 65°W),  
 and (d): PAPA (50°N, 145°W).

*X. Niu, R. T. Pinker, and M. F. Cronin, 2010. Radiative fluxes at high latitudes GRL, 37, L20811.*

Unique problems at high latitudes: Differences in albedo between sea ice and the ocean drive the ice-albedo feedback.

*(Perovich and Richter-Menge, 2008)*



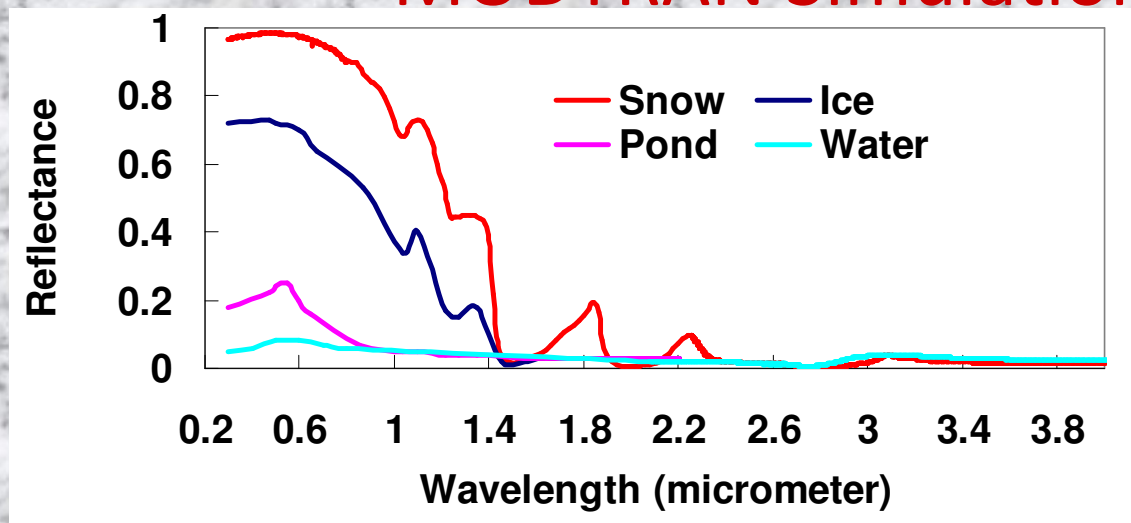


The original MODIS model as described in *Wang and Pinker (2009)* was optimized for polar regions using updated information on of snow and sea ice (*Cavalieri et al., 2008*). .

Updated version described in:

*Niu, X. and R. T. Pinker, 2011. Radiative Fluxes at Barrow, Alaska: A Satellite View. J. Climate, JOURNAL OF CLIMATE, 24 (21), 5494-5505, DOI: 10.1175/JCLI-D-11-00062.1*

# Surface Types and Albedos Implemented in MODTRAN Simulations

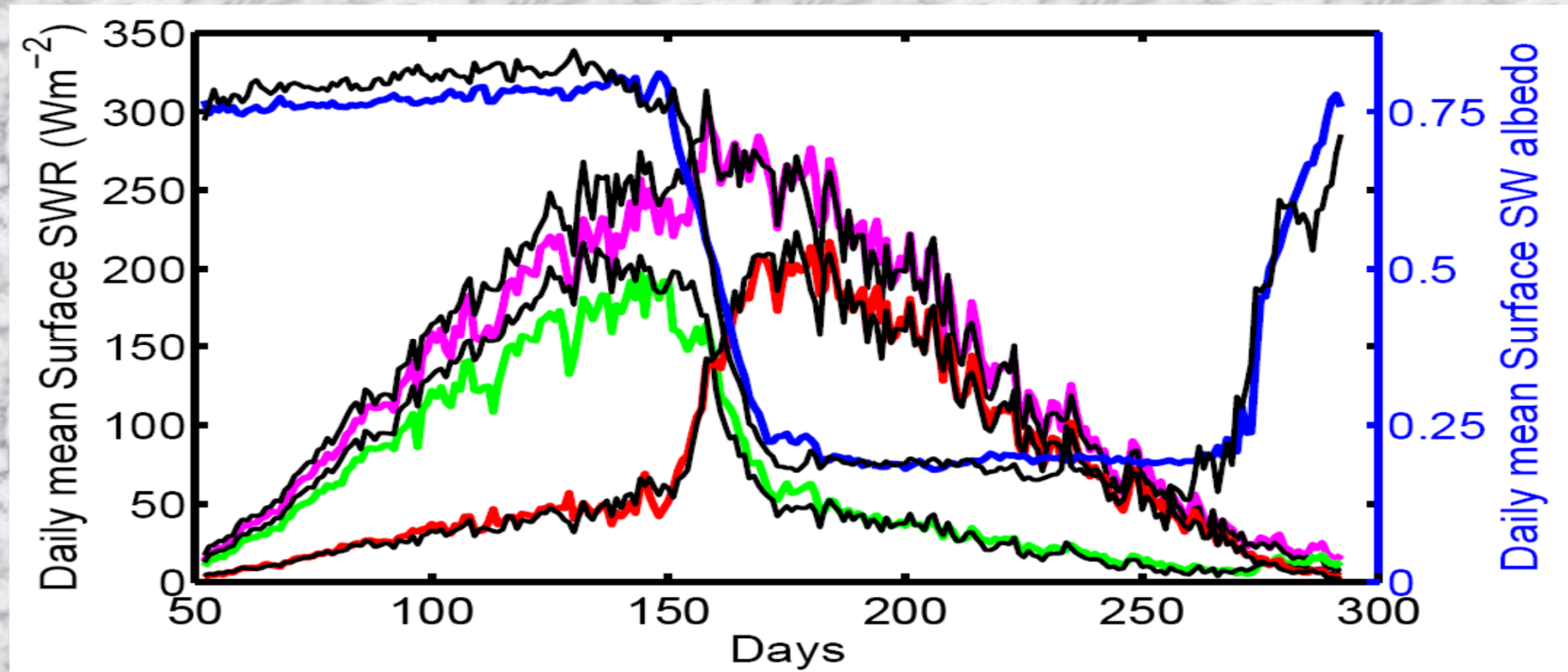


Spectral reflectance of different surface types (snow, ice, pond, water) at High Latitudes

Surface Type	Data Source of Surface Spectral Reflectance
Snow	ASTER SPECTRAL LIBRARY; MODIS products (Moody et al., 2007)
Sea Ice	ASTER SPECTRAL LIBRARY; Cloud Absorption Radiometer from Univ of Washington (King et al., 1996; Arnold et al., 2002)
Melting Pond	Spectral Reflectance measurements near Barrow, Alaska, June 2004 (Tschudi et al., 2008)
Water	ASTER SPECTRAL LIBRARY



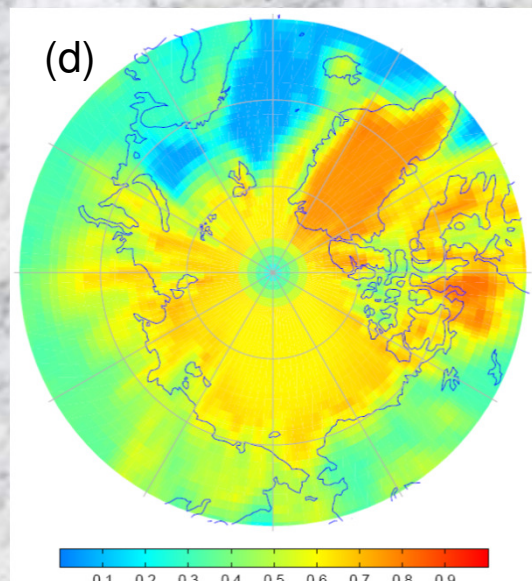
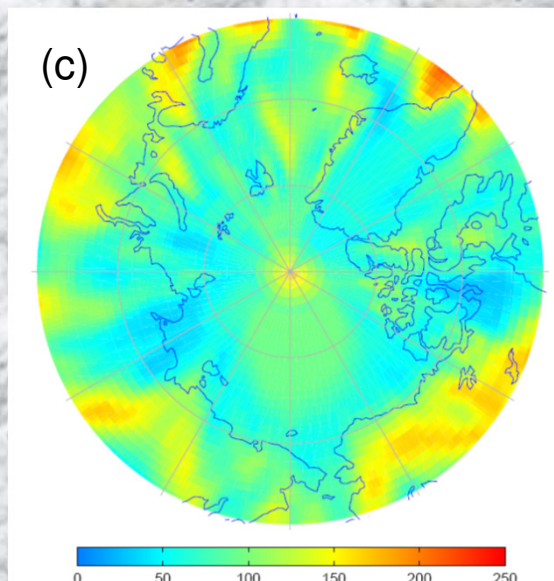
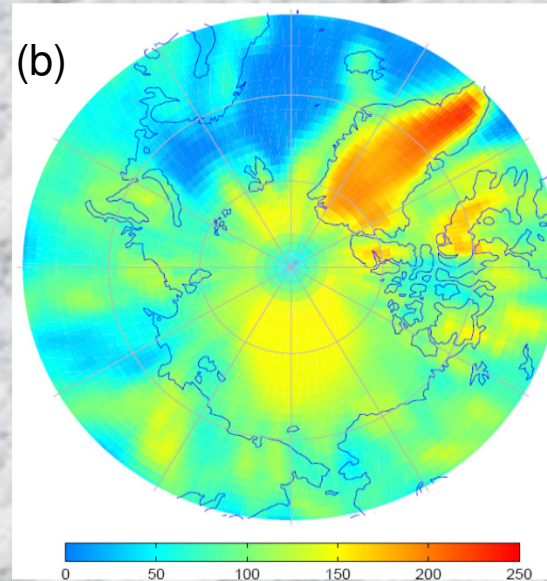
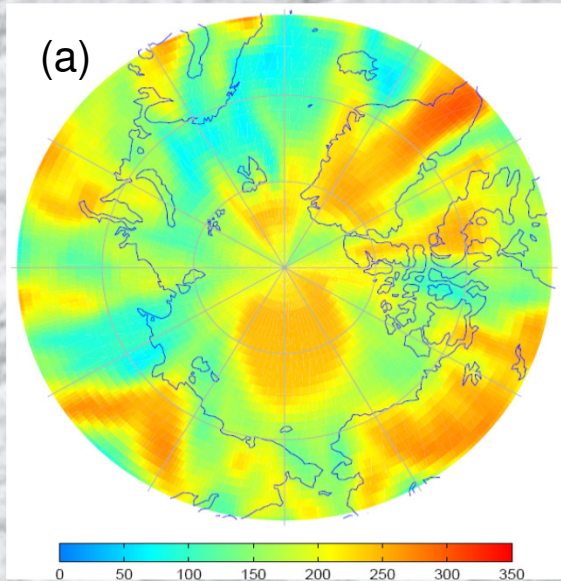
Evaluation of daily mean surface parameters from UMD\_MODIS averaged over 8 years (magenta:  $SWR^{\downarrow}$ ; green:  $SWR^{\uparrow}$ ; red: net  $SWR$ ; blue: surface albedo) against DOE Atmospheric Radiation (ARM) surface observations (black line) at Barrow, Alaska.



Used data as described in:

Dong, X., B. Xi, K. Crosby, C. N. Long, R. S. Stone, and M. D. Shupe, 2010: A 10 year climatology of Arctic cloud fraction and radiative forcing at Barrow, Alaska. *J. Geophys. Res.*, 115, D17212, doi:10.1029/2009JD013489.





Products derived from  
UMD\_MODIS (1°) over  
the Arctic regions (60°N-  
90°N) for May 1, 2007:

(a): daily mean surface  
downward SWR ( $\text{Wm}^{-2}$ )

(b): daily mean surface  
upward SWR

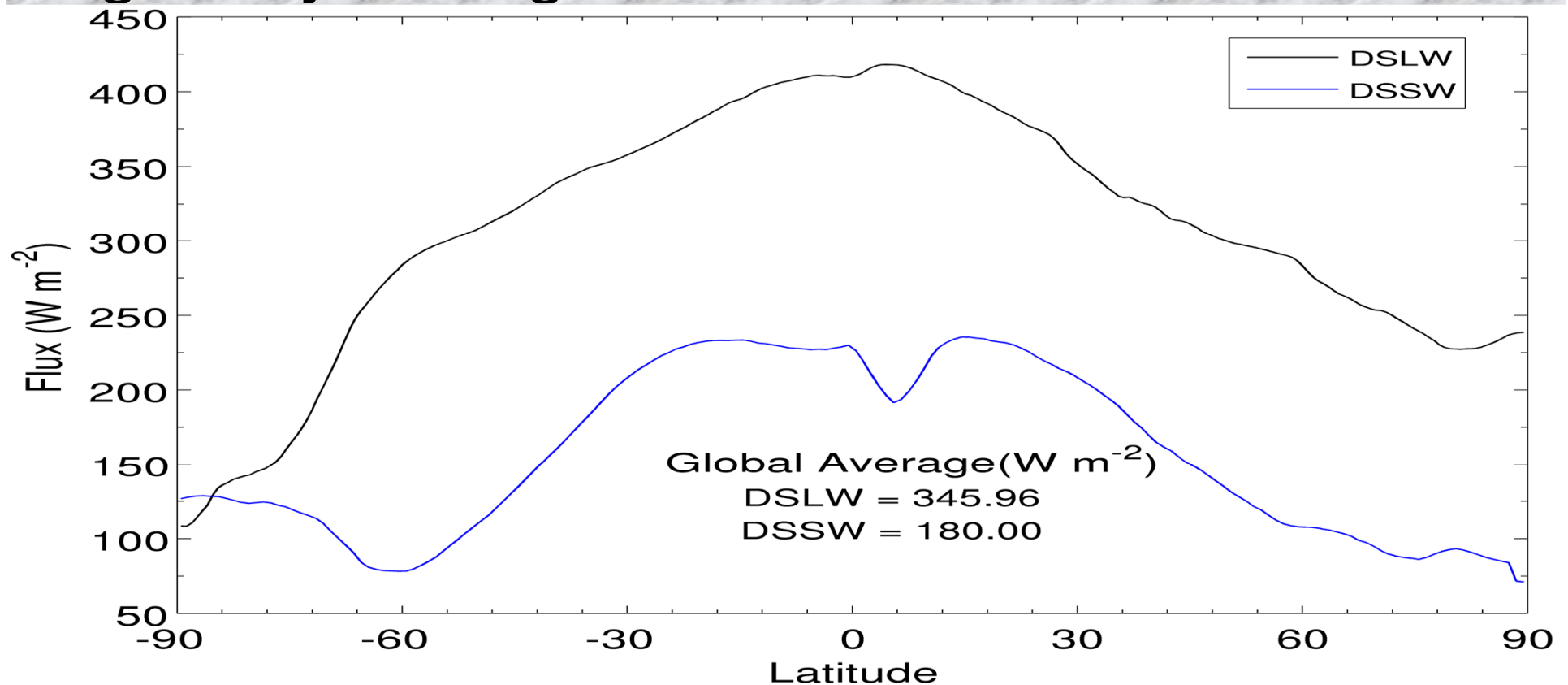
(c): daily mean surface  
net SWR

(d): surface albedo

*(Niu and Pinker 2011)*



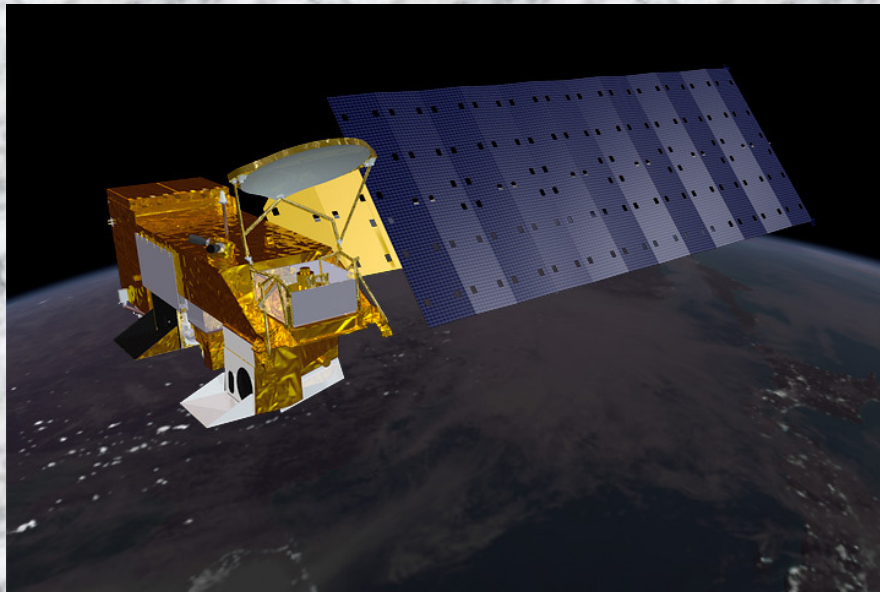
Downwelling Surface Longwave Radiation (DSLW) is among the **largest components** of globally averaged surfaced radiation balance



Daily values averaged over 2007 as derived from MODIS at the University of Maryland 23

# Satellite Observation of Clouds

- Passive Satellite
  - Global spatial coverage
  - Cloud top properties
- Active Satellite
  - Limited coverage
  - Cloud vertical structure



Aqua Satellite with Moderate Resolution Spectroradiometer (MODIS)

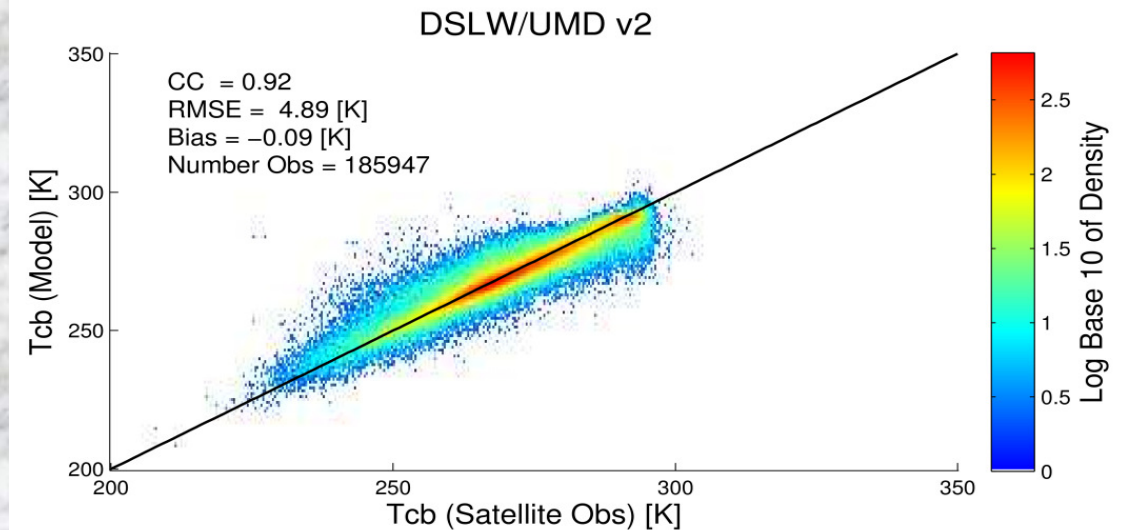


CALIPSO satellite with Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)



# Cloud Vertical Structure Model

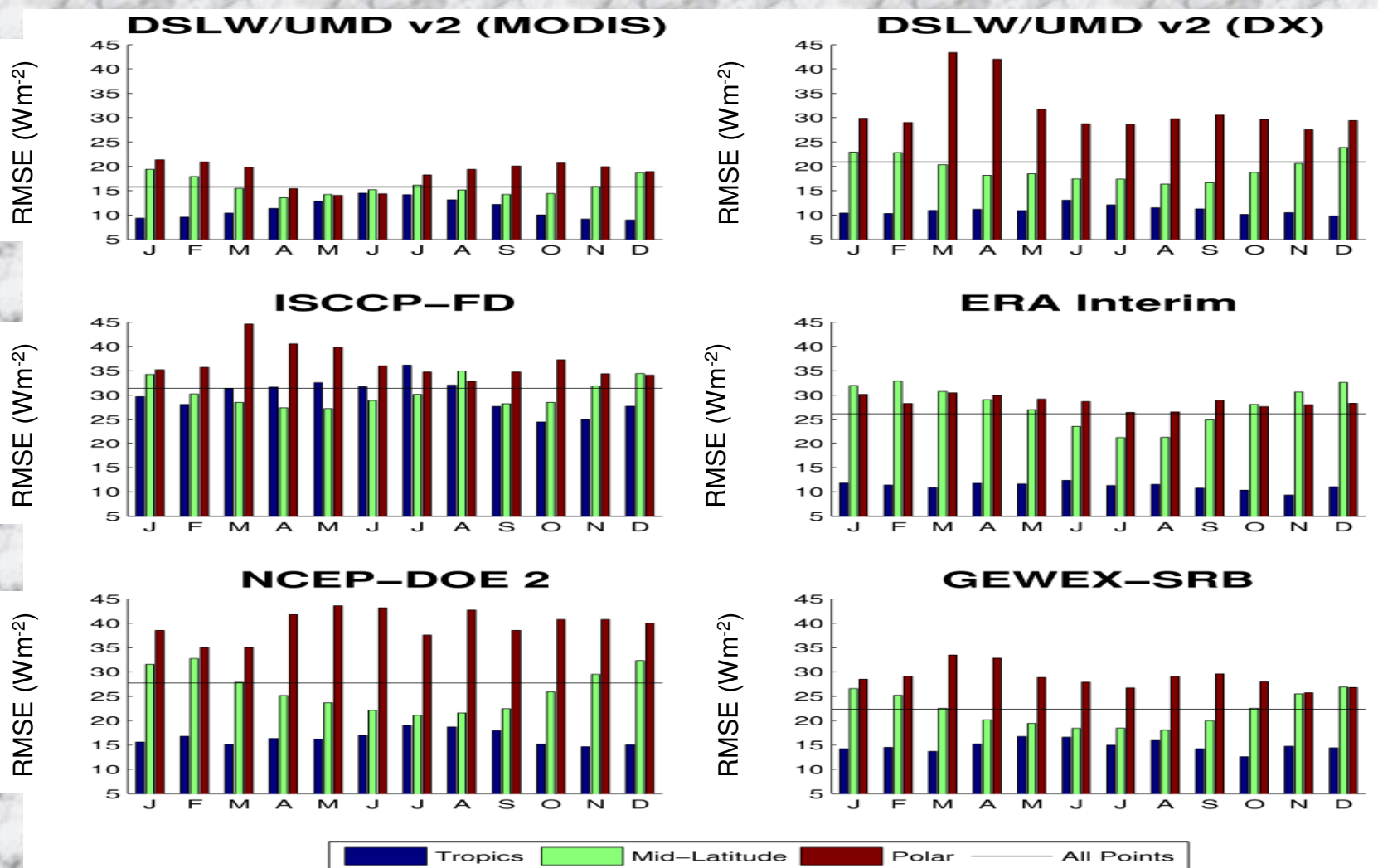
Use Neural  
Network approach  
based on passive  
and active satellite  
data



*Nussbaumer, E. A. and R. T. Pinker, 2011. Estimating surface long-wave radiative fluxes at global scale. Q. J. R. Meteorol. Soc. 137, October 2011 A.*

*Nussbaumer, E. A., and R. T. Pinker, 2012. Estimating surface longwave radiative fluxes from satellites utilizing artificial neural networks. J. Geophys. Res., 117, D07209*

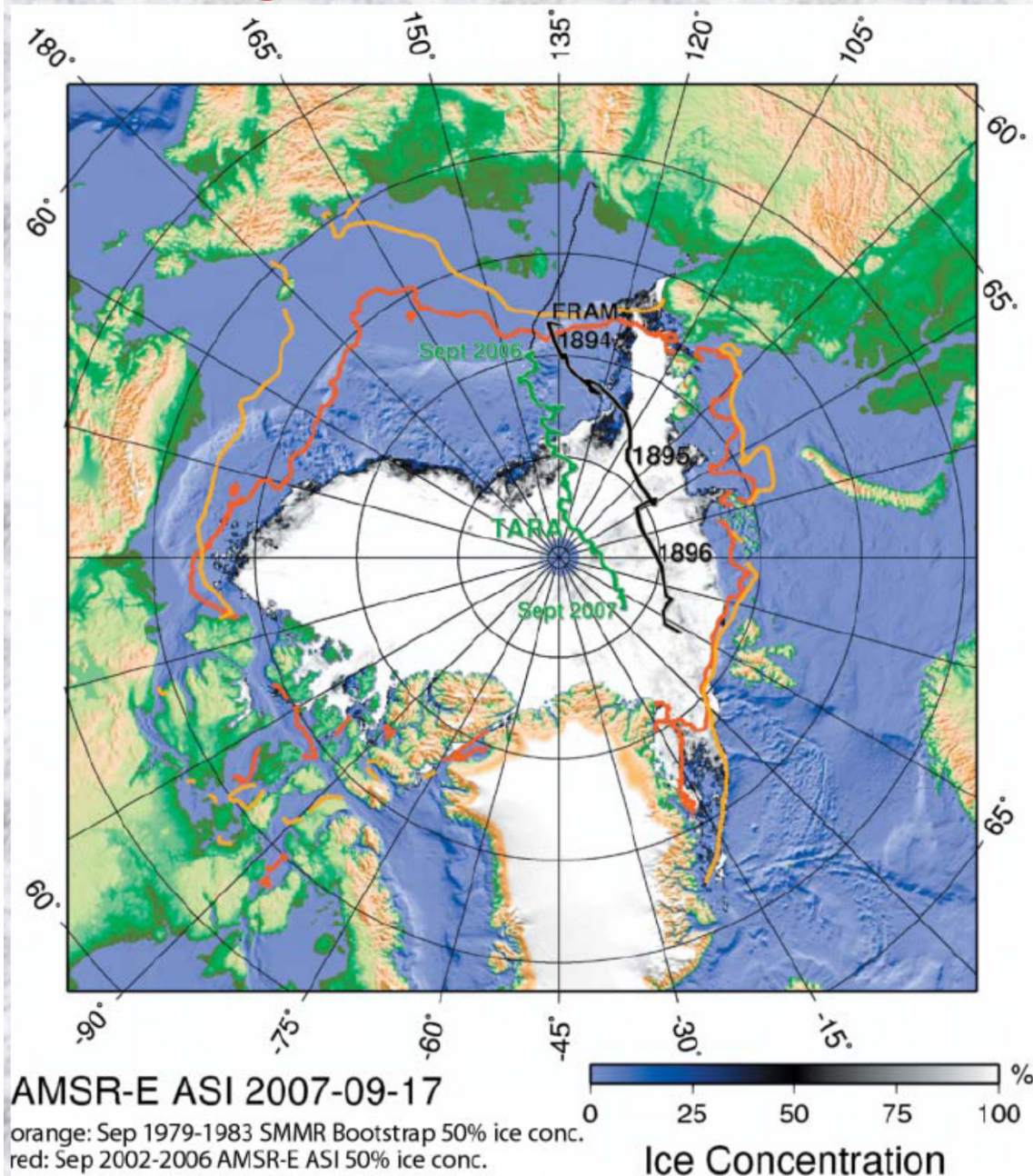
# All Sky Evaluation DSLW/UMD v2: By Latitude using BSRN Observations



From Nussbaumer and Pinker (2012).



# Changes in ice extent: The 2007 Anomaly



The drift track of ice station Tara from Sep 2006 through Sep 2007 and the sea ice summer minimum extent in 2005 and 2007 (*Gascard et al., 2008*):

Orange: Sep **1979-1983** SSMR Bootstrap 50% ice conc.

Red: **Sep 2002-2006** AMSR\_EASI 50% Ice conc.



# What is Causing Arctic Sea Ice Anomalies?

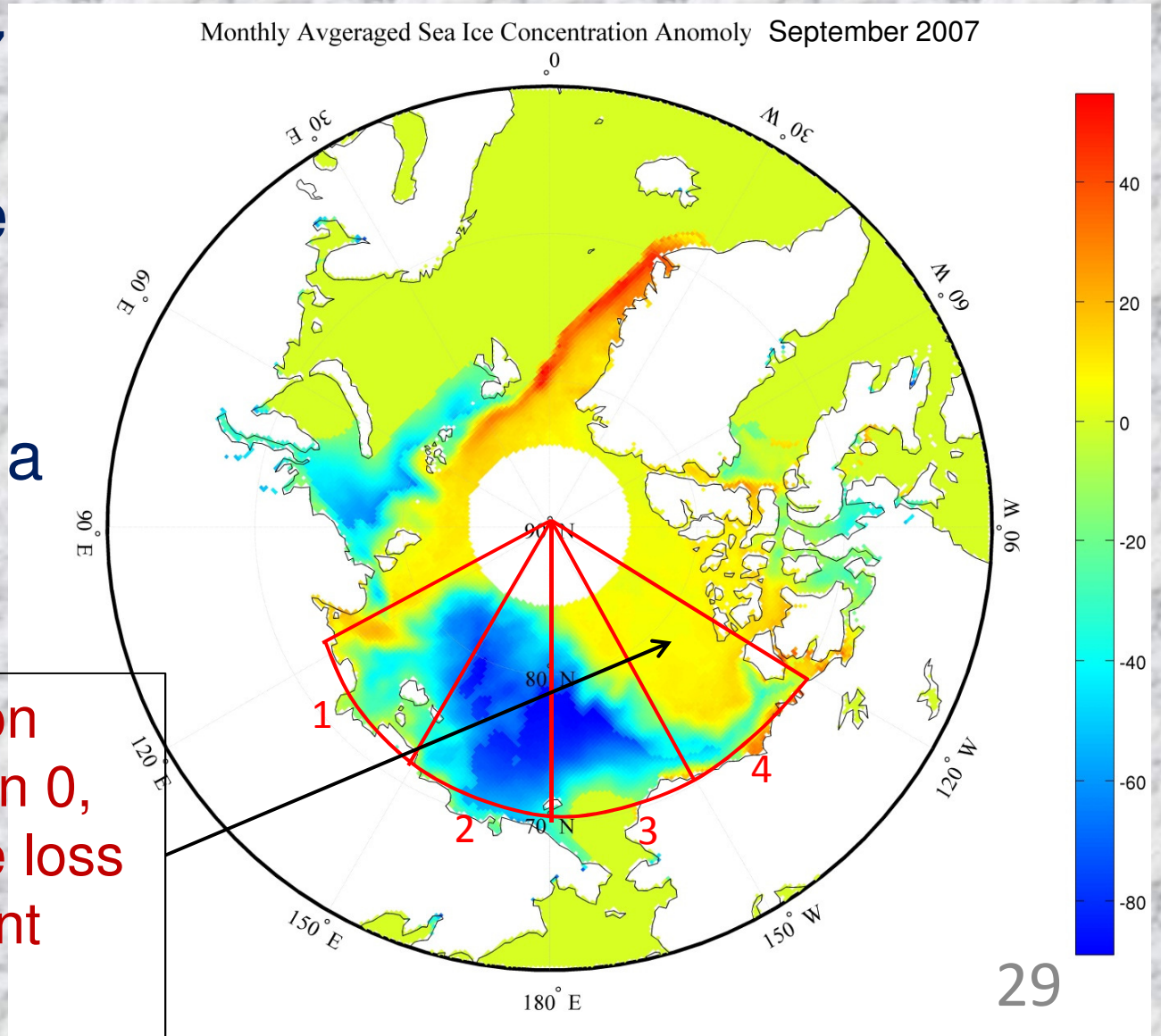
- Arctic sea ice melt is a complex process which depends on multiple factors
  - Decline of thick perennial sea ice (*Nghiem et al., 2007*)
  - Transport of sea ice via wind stress (*Rigor and Wallace, 2004*)
  - Ice-albedo feedback (*Perovich et al., 2008*)
  - Arctic ocean heat transport (*Shimada et al. 2006*)
  - Shortwave and Longwave radiation (*Kay, J., T. L. L'Ecuyere, A. Gettelman, G. Stephens, and C. O'Dell, 2007*), *Schweiger et al. (2008)*, *Francis and Hunter (2006)*], *Stoeve et al. (2008)*.
- Relative contribution of each factor remains unknown.



# Spatial Variability of Sea Ice Anomalies

September 2007  
represents the  
month where the  
sea ice  
concentration  
anomaly reached a  
minimum

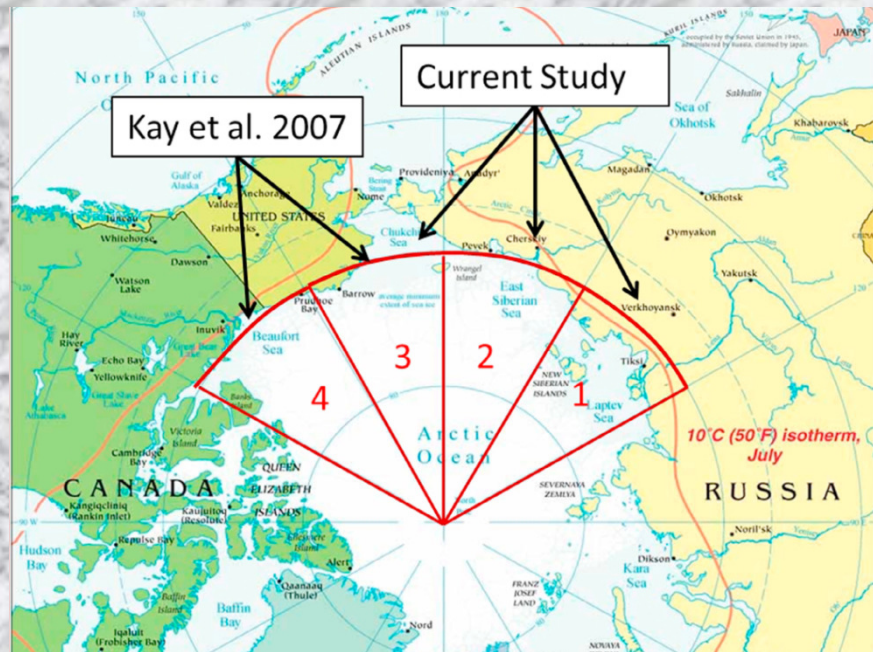
Sea ice concentration  
anomaly greater than 0,  
indicates that sea ice loss  
is not more significant  
than climatology





# Causes of 2007 Arctic Ice Anomaly

## Possibly: SW?



Nussbaumer, E. A., and R. T. Pinker (2012). The role of shortwave radiation in the 2007 Arctic sea ice anomaly, GRL, 39, doi:10.1029/2012GL052415.

Separate the region according to intensity of sea ice anomalies. The region with the strongest signal during 2007 reduction in sea ice is identified as 120E to 210E. **Results:** For 2007, areas of largest accumulation of SW do not correspond with negative sea ice concentration anomalies.

Used MODIS SW<sup>30</sup>



# Application of MODIS PAR for estimating net primary productivity

Terrestrial **net primary production** (NPP) is controlled by **photosynthesis** driven by radiation in the visible part of the spectrum (0.4–0.7  $\mu\text{m}$ ), known as the **photosynthetically active radiation** (PAR).

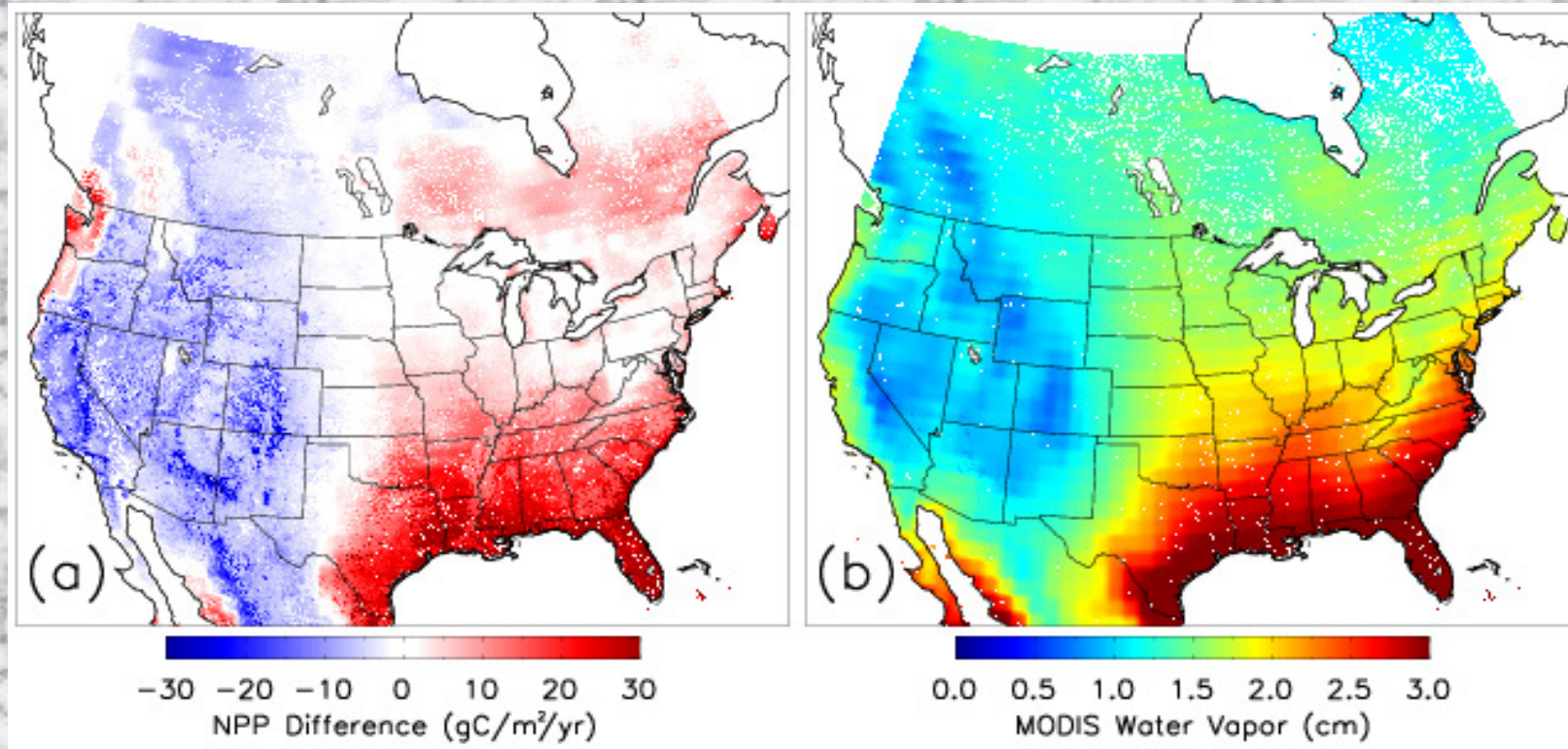
**Current methods** to estimate terrestrial net primary production (NPP) use remotely sensed information on vegetation dynamics only (like the MODIS NPP product). Satellite based estimates of PAR have seldom been used for estimating NPP.

We show that the use of PAR information from satellites does have an impact on estimates of NPP and that there are detectable differences when compared to similar estimates based on conventional PAR information.

To examine the impact of satellite based estimates of PAR on GPP/NPP as compared to 'control runs' obtained with GMAO based estimates of PAR, we use the MODIS GPP/NPP model of the Numerical Terradynamic Simulation Group, University of Montana



## Tested the implications of satellite based estimates of PAR on NPP as available from MODIS



a) The difference between annual total NPP of the two runs (sensitivity minus control); b) The corresponding distribution of average precipitable water in the growing days ( $GPP > 0$ ) as derived from MODIS for same time period. Both figures are the average for years (2003-2005).

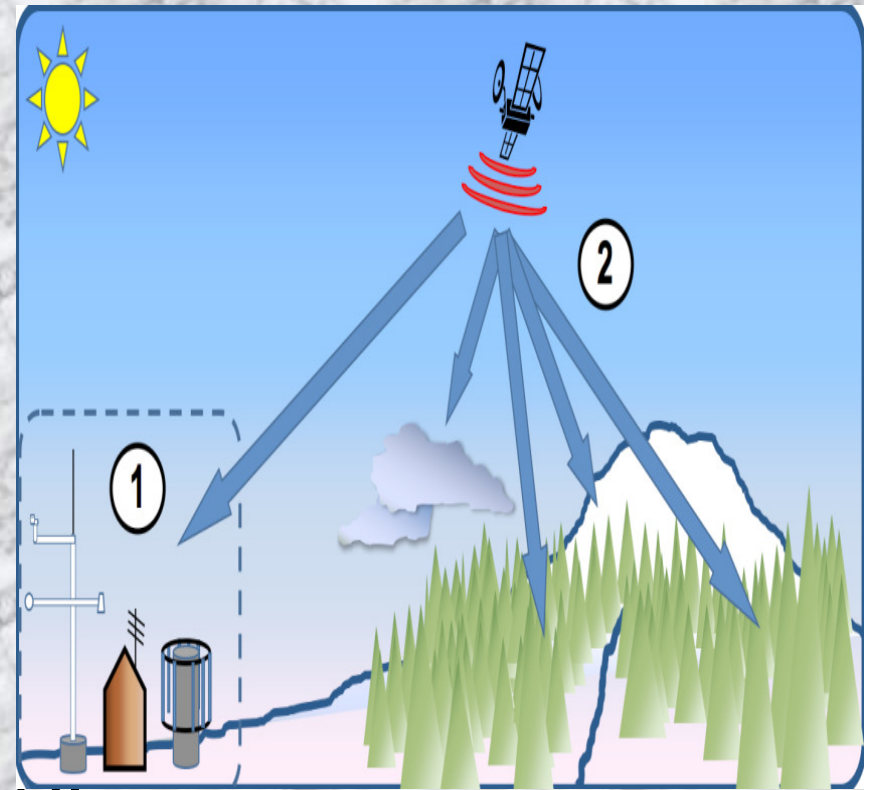
*Pinker, R. T. Maosheng Zhao, Hengmao Wang, Eric F. Wood, 2010. Impact of satellite based PAR on estimates of terrestrial net primary productivity. International Journal of Remote Sensing, Volume 31 Issue 19 2010, Pages 5221 – 5237.*



# Using MODIS and CERES Data to Improve Energy Balance Snowmelt Modeling

## *NASA Terra and Aqua Project*

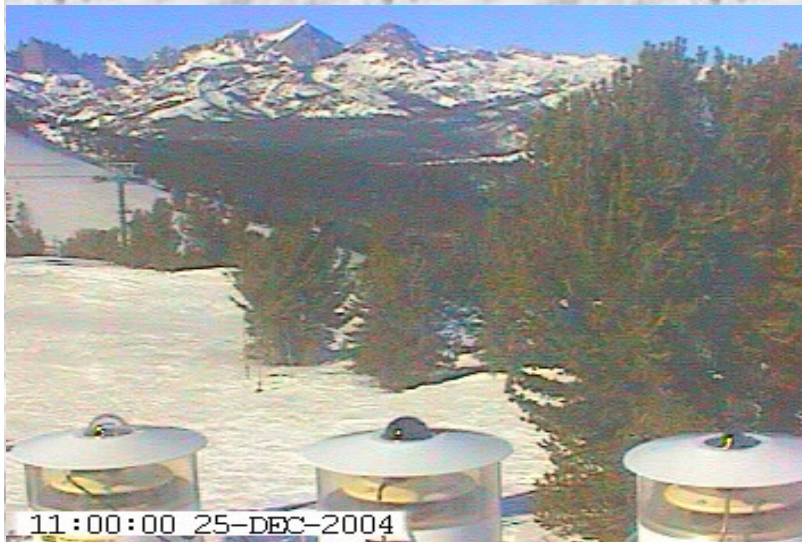
Hinkelman, L. M., J. Lundquist,  
T. Pinker, MODIS Science Team  
Meeting U. Maryland Conference  
Center, College Park, MD, May  
18-19, 2011.



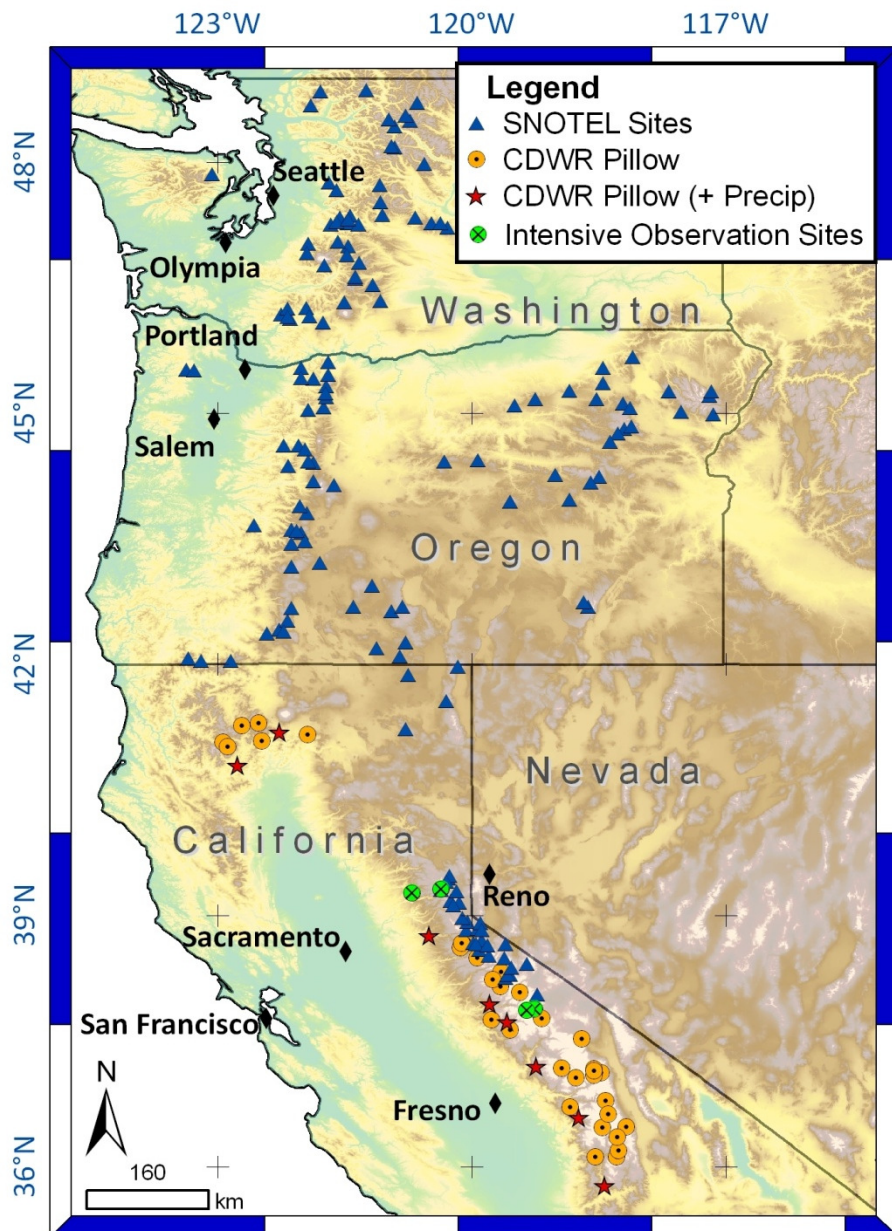


# In Sierra Nevada, radiation dominates the energy balance

## Central Sierra Snow Lab





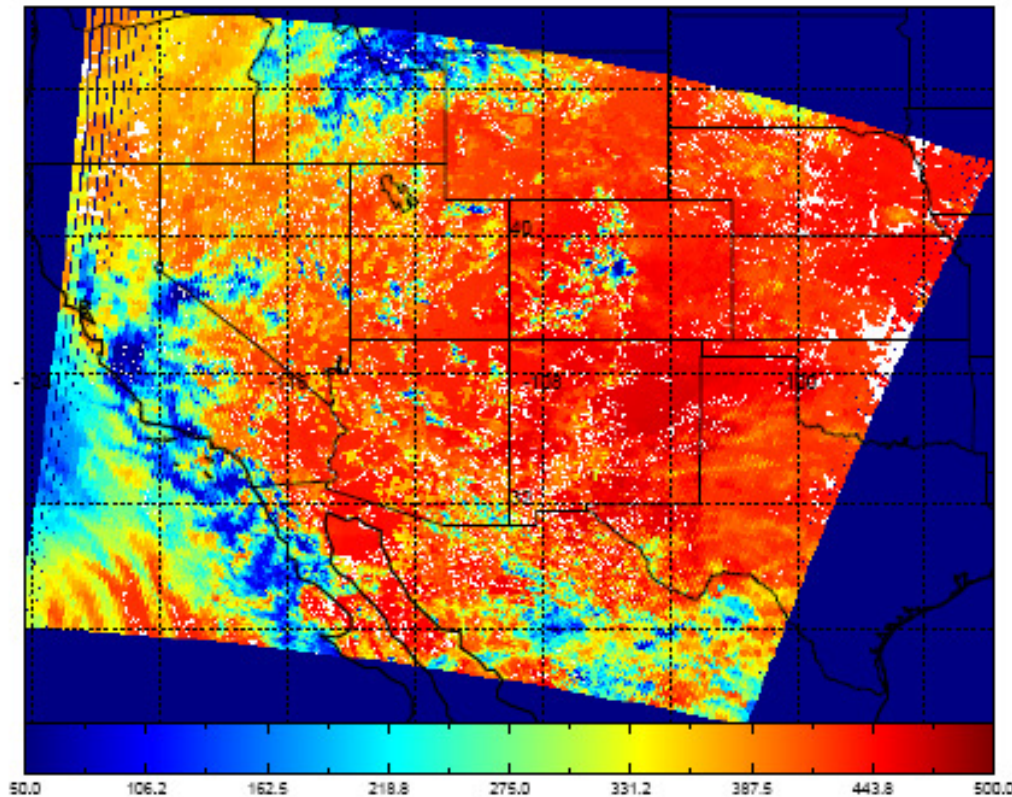


## At Issue

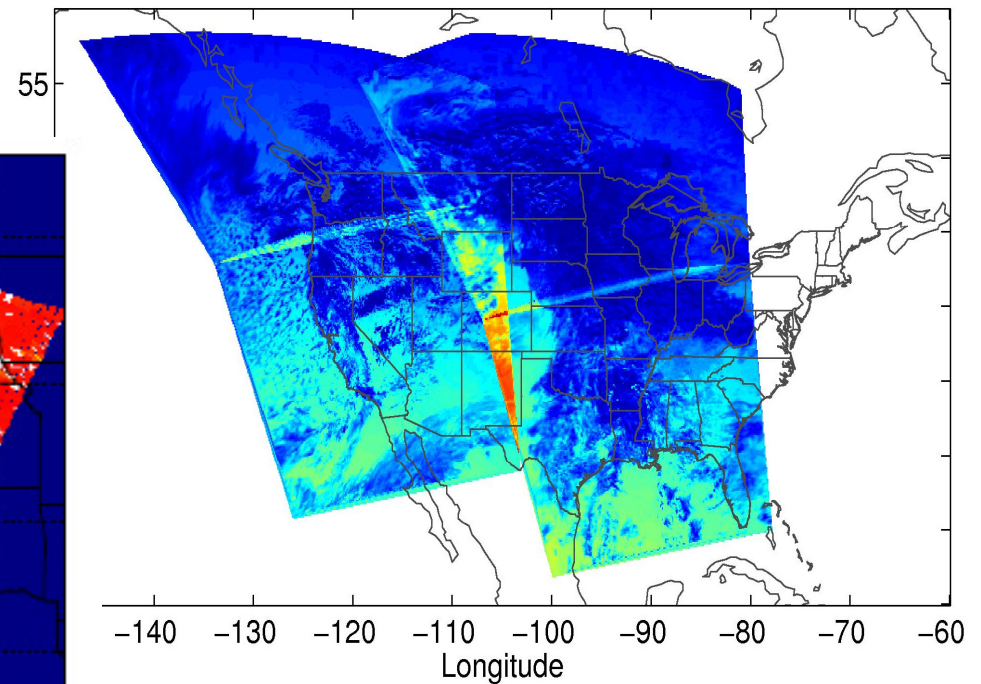
Snowmelt supplies as much as *75% of surface water in basins of the western United States*. *Global Climate Model simulations* show continued *loss of snowpack* as much as 70% by mid-21<sup>st</sup> century. Expected: high resolution information on radiative fluxes will improve snowmelt modeling.



Work in progress: deriving SW  
and LW fluxes at 5-km.



Surface downward PAR  
2001185.1820 ( $\text{W/m}^2$ )



Downward SW radiation  
from MODIS/Aqua  
swaths for 2005.001 at:  
19:15; 19:20; 20:55 and  
21:00 GMT



# Summary

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- “Direct” method for inferring SW radiative fluxes has been developed for implementation with MODIS information at  $1^{\circ}$  resolution for global scale; also applicable to 5-km data.
- Scheme has been modified for high latitudes and evaluated against surface measurements over land and oceans.
- A LW inference scheme has been developed for use with MODIS input and trained with A-Train data to optimize cloud vertical structure .
- Existing information has been applied to a wide range of climate issues and shared with users. 38



# References

Cavalieri, D., C. Parkinson, P. Gloersen, and H. J. Zwally, 2008. Sea ice concentrations from Nimbus-7 SMMR and DMSP SSM/I passive microwave data. National Snow and Ice Data Center, Boulder, CO, digital media.

Francis, J. A. and E. Hunter, 2006. New insight into the disappearing Arctic sea iceEOS, TRANSACTIONS AMERICAN GEOPHYSICAL UNION, VOL. 87, NO. 46, 509, 2006

Gascard, J. C., and Coauthors, 2008. Exploring Arctic transpolar drift during dramatic sea ice retreat. Eos, Trans. Amer. Geophys. Union, 89, 21–28.

Kay, J. E., T. L'Ecuyer, A. Gettelman, G. Stephens, and C. O'Dell, 2008. The contribution of cloud and radiation anomalies to the 2007 Arctic sea ice extent minimum, Geophys. Res. Lett., 35, L08503.

King, M. D., W. P. Menzel, Y. J. Kaufman, D. Tanré, et al., 2003. Cloud and Aerosol Properties, precipitable Water, and Profiles of Temperature and Humidity from MODIS, *IEEE Trans. Geosci. Remote Sens.*, 41, 442-458.

McPhaden, M. J., et al., 1998. The Tropical Ocean-Global Atmosphere observing system: A decade of progress, J. Geophys. Res., 103, 14,169–14,240.



Moody, E. G., M. D. King, C. B. Schaaf, D. K. Hall, and S. Platnick, 2007. North hemisphere five-year average (2000–2004) spectral albedos of surface in the presence of snow: Statistics computed from Terra MODIS land products, *Remote Sens. Environ.*, 111, 337–345.

Nghiem, S. V., I. G. Rigor, D. K. Perovich, P. Clemente-Colon, J. W. Weatherly, and G. Neumann, 2007. Rapid reduction of Arctic perennial sea ice, *Geophys. Res. Lett.*, 34, L19504, doi:10.1029/2007GL031138.

Ohmura A., E. Dutton, B. Forgan, C. Frohlich, H. Gilgen, H. Hegne, A., Heimo, G., Konig-Langlo, B. McArthur, G. Muller, R. Philipona, C. Whitlock, K. Dehne, and M. Wild, 1998. Baseline Surface Radiation Network (BSRN/WCRP): New precision radiometry for climate change research. *Bull. Amer. Meteor. Soc.*, Vol. 79, No. 10, 2115-2136.

Perovich, D. K., J. A. Richter-Menge, K. F. Jones, and B. Light, 2008. Sunlight, water, and ice: Extreme Arctic sea ice melt during the summer of 2007, *Geophys. Res. Lett.*, 35, L11501, doi:10.1029/2008GL034007.

Rigor, I. G., and J. M. Wallace, 2004. Variations in the age of Arctic sea ice and summer sea-ice extent, *Geophys. Res. Lett.*, 31, L09401,



Schweiger, A. J., J. Zhang, R. W. Lindsay, and M. Steele, 2008. Did unusually sunny skies help drive the record sea ice minimum of 2007? *Geophys. Res. Lett.*, 35, L10503, doi:10.1029/2008GL033463.

Shimada, K., T. Kamoshida, M. Itoh, S. Nishino, E. Carmack, F. A. McLaughlin, S. Zimmermann, and A. Proshutinsky, 2006. Pacific Ocean inflow: Influence on catastrophic reduction of sea ice cover in the Arctic Ocean, *Geophys. Res. Lett.*, 33, L08605.

Stroeve, J., M. Serezze, S. Drobot, S. Gearheard, M. Holland, J. Maslanik, W. Meier, and T. Scambos, 2008). Arctic sea ice plummets in 2007, *EosTrans. AGU*, 89 (2), 13, doi:10.1029/2008EO020001.